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Analogies in High School Classes on Quantum Physics

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Abstract

This paper presents preliminary findings of research on using analogies in high school classes on quantum physics. Use of analogies in teaching activities has been proposed in science education research as a method to construct appropriate meanings from and through science representations. We can find in the literature several articles where using such analogies requires some care in order to help in the learning process of concepts presented. However, we contend that in Modern and Contemporary Physics (MCP) we find some epistemological and/or ontological obstacles when trying to represent quantum entities, for example. Our purpose is, based on data gathered through the recording of classes on quantum physics at high school, and using categories from Curtis & Reigeluth (1984), to search for the common analogies that are used. We obtained transcriptions from the classes of teachers from different public schools in São Paulo. The identification of some features of a possible classification might help in the teacher training as well as in teaching of quantum physics. We highlight that it is essential that the teacher be aware of his/her actions. The recognition of some characteristics of the different representations may contribute to make the teacher's actions less and less alienating and enable sharing of the meaning with students.

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1. Introduction

In the literature, justifications for using analogies in teaching activities are sometimes based on the observation that, when two or more things are similar in at least one way, analogical thinking allows one to draw a conclusion

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about an unknown factor on the basis of resemblance to a familiar or known factor. According to some authors, analogies compose the mechanism of the thought. Even without our awareness, they dictate the choices of words, and help us to understand (to give sense) to everyday situations. According to them, the analogy leads us into unexpected circumstances, inspires our imagination and is also the source of discovery.

However, in accordance with several papers, we emphasize the danger in using analogies in science teaching. We highlight some problems that appear when the analogous (that which represents the object) is unknown to the student or, when they construct similarity relations based on their observations and when these relationships are different from teacher intentions. Above all, the risks are even greater if the academic content is quantum physics, where the entities or concepts presented to students do not have any relation with the immediate experience of the sensible world.

Scientists conceptualize analogy differently. According Poincaré, the set of analogies can be classified according to different levels: from “primitive analogies” about immediate sense impressions, to “mathematical analogies” which maintain a structure's relations, not just the simple appearance's relation. For him the primitive analogies usually are just a brief comparison, which make use of the imagination not the reasoning. Nevertheless, the analogies in the more elaborate sense (analogies mathematical) are a form of reasoning. They involve representative thinking.

Into this research context, our work highlight some remarks about the use of analogies in physics classes, above all, about the use of analogies intend to present concepts of quantum physics. We seek in the epistemology of science some collaboration, admitting that there are similarities between the knowledge production activities and your communication.

Our data are obtained from video records of high school classes on quantum physics at public schools in São Paulo, Brazil. We selected episodes where the teachers used analogies in order to explain a concept of quantum physics. We made a first categorization based on a Curtis’ article entitled: “The Use of Analogies in Written Text”, and, from these categories, we made a brief analysis. Finally, we point out the possibility of creating new categories based on our theoretical frameworks in order to contribute to the present theme, the use of analogies in quantum physics classes.

2. Analogy and meaning

We are constantly faced with a swirling and intermingling multitude of ill-defined situations. Our brain’s job is to try to make sense of this unpredictable, swarming chaos of stimuli. How does it do so? According Hofstadter & Sander (2013), the ceaseless hail of input triggers analogies galore, helping us to pinpoint the essence of what is going on. Often this means the spontaneous evocation of words, sometimes idioms, sometimes the triggering of nameless, long-buried memories. Analogy-making, far from happening at rare intervals, occurs at all moments, defining thinking from top to toe, from the tiniest and most fleeting thoughts to the most creative scientific insights.

We present some considerations about the use of analogy and categorization in the construction of concepts. We do not agree with the idea that categories are a static set characterized by their labels. In our perspective, category represents a dynamic mental structure that changes, sometimes slowly, sometimes quickly, but that maintain, overall, an organized structure. The categorization process is temporary, hierarchical, and consists in associating a new entity or situation with a category already existing in the cognitive structure of the subject. This process occurs in the "recognition" of similarities between the "new thing" and the set that we call "mental things". Indeed, the "things of the world" will always be understood when linked to existing concepts (even if temporary) in the mental structure of the "learner". So when we refer to "things" it will always be about "concepts of things" or "mental things".

In order to explain the formation of concepts in the cognitive structure, we adopt a perspective in which the categorization and the analogy must be analyzed together. From this perspective, we propose as a unit of analysis the dialectical pair categorization / analogy. We highlight that this dialectical pair is in constant movement, i.e., constantly changing. This movement can account for phenomena from simplest cognitive recognition of a "familiar" object to the more sophisticated discoveries of the human spirit. The latter includes the acquisition of new knowledge.

3. Analogy in science teaching

Until now we have presented what the role of analogies in thought is. In this case they are involuntary and uncontrollable. Otherwise, in teaching activities the use of analogies is conscious and can be planned. If our first proposition, that the dialectical pair categorization / analogy plays a key role in the concept formation process, is true, then analogies appear as potential tools to help the understanding of new concepts presented to the learner in science teaching.

Rigolon and Obara (2011) present the Teaching With Analogies (TWA) model, developed by Glynn in 1991 and redesigned by Glynn et al., in 1994, and point out a certain structure that gives the use of analogies in teaching science the status of a tool with great potential. In order to reinforce the relevance of this topic, Glynn et al. (1994) established the steps that can help teachers use analogies systematically and effectively: 1. Introduce the target concept to students; 2. Remind students of what they know of the analog (vehicle) concept; 3. Identify relevant features of the vehicle; 4. Connect (map) the similar features of the analog and the target; 5. Indicate where the analogy between the analog and the target breaks down; 6. Draw conclusions.

The authors reiterate the importance of the use of analogies as an auxiliary tool to the teacher. They emphasize that, by its own methodology, the use of analogies could help us understand the role of memory in the assimilation of new concepts, particularly in science teaching and, moreover, minimize the activity of student memorization.

Several studies have reinforced the potential of this tool in the teaching and learning of science (eg Duit, 1991; Glynn, 1989; Harrison and Treagust, 2006), primarily of concepts with a higher degree of complexity. However, there are also studies that report some problems in the use of analogies in teaching activities (eg Duarte, 2005; Brown and Clement, 1989).

In an attempt to synthesize this topic, we highlight some points regarding the advantages of analogy use in science teaching in contrast with difficulties and problems. According to Duarte (2005), some points used to defend the use of analogies in science teaching are as follows:

- They lead to the activation of analogical reasoning, organize perception, develop cognitive skills such as creativity and decision making;
- They make scientific knowledge more intelligible and plausible, facilitating the understanding and visualization of abstract concepts and, moreover, they can promote student interest;
- They are a powerful and effective tool in order to contribute to the process of conceptual change;
- They allow for the highlighting of any misconceptions;
- They can be used to assess the knowledge and understanding of students.

On the other hand are also pointed out some difficulties and problems faced by using of analogies in science teaching. We try to summarize them in the following topics:

- The analogy can be interpreted as the concept, or we can just retain the most obvious and appealing details;
- Sometimes analogical reasoning does not work;
- The analogy may not be recognized as such, not making explicit its usefulness;
- Students can focus just on the “positive aspects”.

4. Methodology

In order to analyze analogy use in teaching activities in quantum physics classes, we obtained transcriptions from the classes of some teachers from different public schools in São Paulo. The themes discussed by the teachers were: (i) wave particle duality and photoelectric effect, (ii) atomic models and quantization of energy. The classes were aimed at students in the 10th grade, both of them at public schools in Sao Paulo. The students' age range was between 17 and 18 years old. We generated a categorization of the analogies used in teaching activities based on the work of Curtis and Reigeluth (1984)† entitled The Use of Analogies in Written Text. We used categories comprising two sets. The first group of categories describes the nature of the analogies (fig.1) and the second describes the use of the analogies in physics classes (fig.2).

Standard	Categories	Description
Nature of vehicle	Within of Physics Domain	*The vehicle belongs to the scientific field even though it's from another topic.*
	Different of Physics Domain	*The vehicle doesn't belong to the scientific field.*
Analogical relationship	Structural	*There are physical's similarities between the vehicle and target.*
	Functional	*The similarities between the vehicle and the target correspond to the operations form.*
	Structural - Functional	*The similarity is the combination of physical constitution and operation.*
Condition	Concrete / Abstract	*The nature of vehicle is concrete and the nature of target is abstract.*
	Abstract / Abstract	*Both of them have abstract nature.*

Fig. 1. Categories – Nature of analogies

Standard	Categories	Description
Presentation format	Verbal	*The analogy is presented exclusively through words (oral or textual).*
	Pictorial - Verbal	*Besides words, the analogy is highlighted by pictures.*
Level of enrichment	Simple	*The most basic level of an analogy is the simple analogy. A simple analogy is usually composed of three main parts – the topic, the vehicle, and a connector such as "is like" or "may be compared to".*
	Enriched	*An analogy can be enriched for the learner by stating the grounds for the analogous relationship between the topic and vehicle. In addition, an enriched analogy may also contain the limitations to the analogous relationship.*
	Extended	*The most complex level of enrichment found is one in which the various grounds of a single vehicle are used to teach more than one topic or when various vehicles are used to explain a single topic. This is termed here an extended analogy.*
Position	Advance organizer	*The analogy appears like introduction of a new topic that will be presented during the teaching activity.*
	Embedded activator	*The analogy appears during the didactic action.*
	Post synthesizer	*The analogy appears at the end of the instruction on a topic. As such, it acts as a post synthesizer for the information preceding it and concludes that topic, after which a new topic is immediately introduced.*

Fig. 2. Categories - The use of the analogies

† Although this paper was written there are 30 years ago, compared to recent systematization of the analogy use in science teaching, we deem it relevant to the questions proposed in our research. Even if this paper was based on analogies present in textbooks, we highlight that the classification propose by the authors meets one of our objectives to collaborate with training teacher.

5. Some data

We select some episodes belonging to our set of transcriptions in order to show, overall, what our categorization was.

Table 1. Classification – teacher A (Nature of analogies)

	Category	Description
Nature of vehicle	Within domain of Physics	… ***Transcription:* light is like a wave**. The vehicle (wave) belongs to Physics domains
Analogical relationship	Structural-functional	… ***Transcription:* light is like a wave**. The similarly is of appearance and they share the similar function (we can say: light works like a wave)
Condition	Abstract/ Abstract	Both of them belong to sets of an abstract's nature

Table 2. Classification – teacher A (The usage of the analogies)

	Category	Description
Presentation format	Pictorial - Verbal	… ***Transcription: "So, we can do it like this, look!" ((the teacher draws the wave representation on the board))*** The analogy is reinforced by pictures.
Level of enrichment	Simple	In this case the teacher uses just a little similarity between the target and the vehicle. He uses the connective "is like".
Position	Embedded activator	***… Transcription: "… light is like a wave, so this is the wave model."*** The analogy is presented during the didactic action.

Table 3. Classification – teacher B (Nature of analogies)

	Category	Description
Nature of vehicle	Outside the domain of Physics	***… Transcription: "…guys, think about raindrops (+) if you look at the rain from far away, you probably see like this, right?"*** The vehicle (the rain) does not belongs to the domains of Physics
Analogical relationship	Structural	***…Transcription: "… ((The teacher draws on the board)) look! It seems to be one continuous thing, right? ... but if we could see the rain closely, we would perceive that it isn't continuous, ... it would be like this… ((The teacher draws on the board)). It is formed from little raindrops. So, look here!! This is the representation of light as we understand it nowadays!"*** The similarly is of appearance.
Condition	Concrete / Abstract	The vehicle belongs to a set of concrete nature (the rain), while the target belongs to a set of abstract nature (the light).

These teachers used analogies spontaneously to explain abstract quantum physics concepts. Nevertheless, we could not find evidence that the use of analogies in their didactic activities had been planned.

Most of the analogies used by these teachers were of the simple-comparison type. Pictorial analogies were frequently used to enhance analog familiarity, and further analog explanation was not uncommon, but we did not find teachers' remarks about analogical limitations.

6. Final remarks

Although we find several papers about the use of analogy in science teaching, we find a gap specifically in the analysis of the use of analogies in themes of quantum physics. We emphasize that this specific approach is very important, as presented earlier, because we understand that in the context of quantum physics we have particular difficulties to represent entities and concepts.

From some results of our research we highlight that the analogies used by the teachers were mostly analogies of form/appearance. We realize that even in cases in which teachers have used analogs that belong to the domain of physics, they made them mostly using physical similarities (appearance), instead of looking at structural similarities. From Bachelard those analogies do not have "strong" relationship with the object of study, represent epistemological obstacles, and do not contribute to the formation of the scientific mind. This problem is greater when we try to use representations in quantum physics. Indeed, subatomic entities have no connection with to images of the "macroscopic world". Thus, we must avoid use them directly.

Our future goal is to seek, from theoretical frameworks, to overcome the appearance of contradiction between Hofstadter & Sander's (2013) perspective, which highlights analogies as the main process of thinking, and Bachelard's (1996) perspective which claims that analogies must be avoided in order to teach science concepts. Although we recognize the potential of the categories here presented, we search to create new ones starting from Poincaré's considerations concerning analogies as well as the concept of a "new status of common sense" according to Paty (2003).

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